# Effect of Wildfires on Soil Erodibility by Wind

## Final Test Report

For

Radian International
Rocky Flats Environmental Technology Site

MRI Project No. 110056.1.004

May 16, 2001

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# Preface

This report was prepared by Midwest Research Institute (MRI) for Radian International under Purchase Order No. 803991. In this report, MRI presents the methodology and results of the wind erodibility testing of an area burned by a wildfire at the Rocky Flats Environmental Technology Site, located northwest of Denver, Colorado.

The work was conducted in MRI's Applied Engineering Division. Dr. Chatten Cowherd, who served as the project leader for MRI, coordinated the preparation of this report. Other MRI technical staff who contributed to the program were Mary Ann Grelinger (data acquisition) and Courtney Kies (data reduction).

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# Section 1. Introduction

The purpose of this study was to determine the impact of a wildfire on the potential for wind-generated particulate emissions from radioactive soils and vegetation at the Rocky Flats Environmental Technology Site northwest of Denver. On the evening of July 10, 2000, a lightning strike in the Rocky Flats buffer zone ignited a wildfire. The fire was controlled after burning 8.4 acres of grassland. The exposed soil surrounding the clumps of burned vegetation was known to contain actinide particles that could be resuspended by wind erosion.

Wind tunnel testing was initiated on August 22, 2000. The MRI reduced-scale wind tunnel was used in performing the tests on the wildfire area, in case contamination from the radioactive elements found in the area required disposal of the wind tunnel at the conclusion of testing. Typically, wind tunnel tests are performed using MRI's primary test device, a larger portable wind tunnel that has served as a reference test device to develop EPA-approved emission factors for wind erosion.

Both the larger and smaller wind tunnels have the same design and incorporate (a) time-integrating air samplers for PM-10 collection, and (b) two TSI DustTRAK monitors to provide real-time concentrations of PM-10 and PM-2.5 in the tunnel effluent. However, the reduced-scale wind tunnel has an open-floored test section that has approximately two-fifths the test area of the larger reference wind tunnel test section. Based on this size difference, initial tests were performed by operating both wind tunnels on an unpaved roadway surface with uniformly textured surface aggregate, so the performance of the two wind tunnels could be compared.

After comparative testing of the two tunnels on the unpaved gravel roadway, the reduced-scale wind tunnel was moved to the wildfire burned area where wind erosion testing was conducted. In addition to the wind tunnel tests that were performed, surface soil samples were collected from the wildfire burned area. Both the soil samples and the filters used in the wind tunnel testing were analyzed for isotopic activity.

The August 2000 test series on the wildfire area was preceded by three test series on a prescribed burn area in the Rocky Flats buffer zone. The prescribed burn tests are reported in a companion report, "Effect of Controlled Burning on Soil Erodibility by Wind." The prescribed burn tests were performed with the larger MRI portable wind tunnel.

The objective of the August tests on the wildfire area was to determine the actual actinide release through wind erosion of burned grassland. The wildfire area provided a scenario to verify the overall conclusions associated with the first series of tests of the prescribed burn area. Moreover, it offered the opportunity to characterize wind erosion emission potential as actinide release potential for different wind speeds.

This report describes (a) the types of equipment and the procedures that were used in the field testing at Rocky Flats and in the laboratory analysis of collected samples at MRI and Rocky Flats, and (b) the field and laboratory test results along with an analysis and interpretation of the results. The report is organized as follows:

- Section 2 describes the equipment and procedures used for field sampling of the wildfire-burned area and for laboratory tests of surface soil samples and PM-10 filters from the wind tunnel testing.
- Section 3 presents the wind tunnel test results along with an analysis and interpretation of the results. The comparative tests of the two different-scale wind tunnels are also described in this section.
- Section 4 presents the laboratory test results together with an analysis and interpretation of the results.
- Section 5 concludes the report with a summary of the test results and the conclusions that can be drawn from the results.
- Section 6 lists the literature references.

# Section 2.
# Test Methods

Field tests were performed to observe the effect of wind speed on the particulate emissions generated from wildfire-burned grassland area at Rocky Flats. The impact of the wildfire on surface soil exposure to wind generated emissions was evaluated using MRI's reduced-scale wind tunnel along with two TSI DustTRAK monitors.

Additional field tests were performed on an unpaved roadway surface with uniformly textured surface aggregate (i.e., raked gravel). These tests were performed using the two different-scale wind tunnels to characterize the performance of the reduced-scale wind tunnel in comparison to the larger-scale reference wind tunnel employed during the prescribed burn tests of April-June 2000.

## 2.1 Wind Tunnel Sampling Equipment

The MRI portable pull-through wind tunnel, as described in the *Air/Superfund National Technical Guidance Study Series, Volume II, Estimates of Baseline Air Emissions at Superfund Sites* (USEPA, 1989), was used in performing the field study of wind-generated emissions from a prescribed burn area in April through June of 2000. This MRI reference wind tunnel (Figure 1) features all of the required design and operating characteristics, including the equipment for extracting isokinetic samples of wind generated particulate matter for measurement of mass emissions and particle size distribution. It is powered by a gasoline engine with direct mechanical linkage to the primary blower, which pulls the airflow through the tunnel.

The MRI reference wind tunnel is identical in design to that developed by Gillette (1978) but is nearly twice as large. It consists of a two-dimensional 5:1 contraction section, an open-floored working section with a 30-cm by 30-cm cross-section, and a roughly conical diffuser. The test area of this tunnel (30 cm by 3.1 m) provides for its use on rougher surfaces. The tunnel centerline airflow is adjustable up to an approximate maximum speed of 19 m/s (40 mph), as measured by a pitot tube at the downstream end of the test section. The equivalent wind speed at a reference height of 10 m above the ground is approximately two to three times the speed at the tunnel centerline, depending of the roughness height of the surface being tested.

The MRI reduced-scale wind tunnel is similarly designed but has a smaller working section (15-cm x 2.44-m open floor) and flow cross-section (15-cm by 15-cm). The ratio of the working areas of the two tunnels is 0.40. An industrial blower powers the reduced-scale tunnel and is driven by an electric motor with a speed control. A gasoline powered electric generator supplies power to the blower motor.

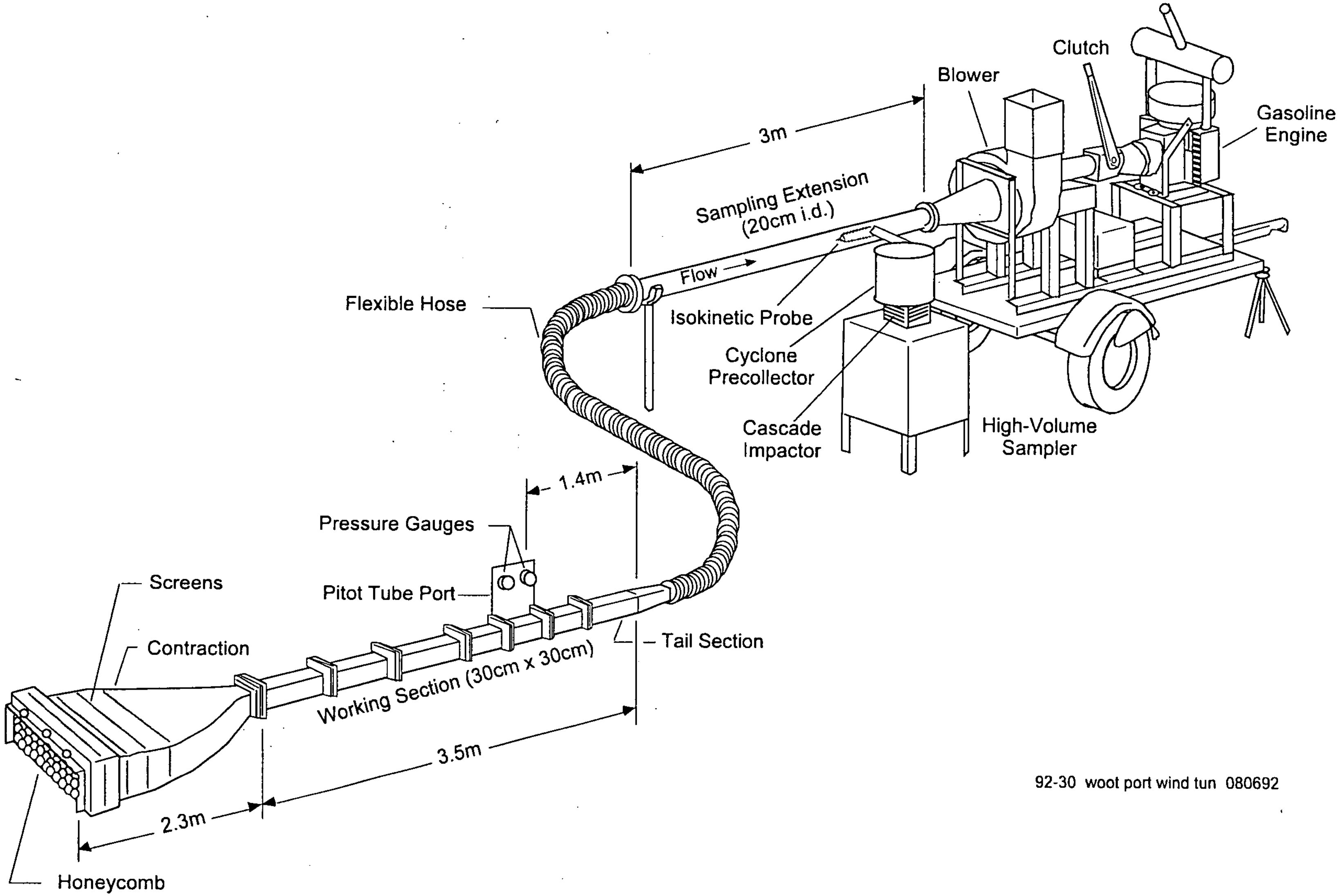


**Figure 1. MRI Portable Reference Wind Tunnel**

In operating both the reduced-scale and reference wind tunnel, the open-floored test section is placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. The exit air stream from the test section passes through a circular duct fitted with a sampling probe near the downstream end. Air is drawn through the probe by a high-volume sampling train that separates total airborne particulate (TP) emissions into two particle size fractions: particles larger than 10 μm in aerodynamic diameter that are collected inside a cyclone, and particles smaller than 10 μm in aerodynamic diameter (PM-10) that are collected on a backup filter under the cyclone.

A high-volume ambient air sampler is operated near the inlet of the wind tunnel to provide for measurement and subtraction of the contribution of the ambient background particulate level. By sampling under light ambient wind conditions, background interferences from upwind erosion sources can be minimized.

The wind tunnel method relies on a straightforward mass balance technique for calculation of emission rate and no assumptions about plume configuration are required. This technique provides for precise study of the wind erosion process on specific test surfaces for a wide range of wind speeds. Previous wind erosion studies using the MRI reference wind tunnel have led to the EPA recommended emission factors presented in *Compilation of Air Pollutant Emission Factors (AP-42)*, published by U.S. EPA (1995).

Although the reference wind tunnel and the reduced-scale tunnel do not generate the larger scales of turbulent motion found in the atmosphere, the turbulent boundary layer formed within the tunnels simulates the smaller scales of atmospheric turbulence. It is the smaller scale turbulence that penetrates the wind flow in direct contact with the erodible surface and contributes to the particle entrainment mechanisms.

The wind speed profiles near the test surface (tunnel floor) and the walls of the tunnel have been shown to follow a logarithmic distribution (Gillette, 1978):

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \qquad (1)$$

where: $u$ = wind speed, cm/s
$u^*$ = friction velocity, cm/s
$z$ = height above test surface, cm
$z_0$ = roughness height, cm

The friction velocity, which is a measure of wind shear at the erodible surface, characterizes the capacity of the wind to cause surface particle movement. As indicated from Equation 1, the wind velocity at any fixed height above the surface (but below the centerline of the wind tunnel) is proportional to the friction velocity. The "micro-scale" roughness height of each test surface is determined by extrapolation of the logarithmic wind speed profile near the surface to where $u = 0$ cm/s.

An emissions sampling module (referred to in Figure 1 as the sampling extension) provides for representative extraction and aerodynamic sizing of particulate emissions generated by wind erosion. The sampling module is located between the tunnel outlet hose and the fan inlet. The particulate sampling train, which is operated at 68 $m^3/h$ (40 acfm), consists of a tapered probe, cyclone precollector, glass fiber backup filter, and high-volume motor. The sampling intake is pointed into the air stream, and the sampling velocity is adjusted to the approaching air speed by fitting the intake with a nozzle of appropriate size.

When operated at 68 $m^3/h$ (40 cfm), the cyclone has a nominal cutpoint of 10 $\mu m$ aerodynamic diameter, based on laboratory calibration (Baxter et al., 1986). Thus the particulate fraction that penetrates the cyclone constitutes PM-10.

A pitot tube is used to measure the centerline (CL) wind speed in the sampling extension, upstream of the point where the sampling probe is installed. The volumetric flow rate through the wind tunnel is determined from a published relationship (Ower and Pankhurst, 1969) between the centerline (maximum) velocity in a circular duct and the average velocity, as a function of Reynolds' number. Because the ratio of the centerline wind speed in the sampling extension to the centerline wind speed in the working section is nearly independent of flow rate, the ratio can be used to determine isokinetic sampling conditions for any flow rate in the tunnel.

A portable high-volume air sampler with an open-faced glass fiber filter is operated on top of the tunnel inlet section to measure background levels of total suspended particulate matter (TSP). The aerodynamic cutoff diameter of TSP is usually assigned a value of 30 $\mu m$. The filter is vertically oriented, parallel to the tunnel inlet face. Based on historical data from Rocky Flats (Haines, 2001), 38.95% of the mass collected on the upwind, background filter is PM-10. The total mass collected represents total suspended particulate matter (TSP). The sampler is operated at 68 $m^3/h$ (40 cfm).

## 2.2 Wind Tunnel Sampling Procedure

Prior to each test series, the working section of the tunnel is placed directly on the selected test surface. To prevent air infiltration under the sides of the open-floored section, the rubberized skirts, attached to the bottom edges of the tunnel sides, are stretched out on the surface adjacent to the test surface. Rubber inner tubes filled with sand are laid along the skirts to assure a tight seal.

With the tunnel in place, the airflow is gradually increased to the threshold for the onset of wind erosion. If a wind erosion threshold exists, the threshold velocity is determined by visual observation of migration of coarse particles. A wind speed profile is measured at a sub-threshold velocity to determine the surface roughness height. In the absence of a clearly evident threshold velocity, the wind speed profile is measured at a tunnel centerline wind speed of approximately 9 m/s (20 mph).

The measured micro-scale roughness height allows for conversion of the tunnel centerline wind speed to the equivalent friction velocity and to the equivalent wind speed at a standard 10-m height, using the logarithmic wind speed profile. If the terrain roughness (rolling hills, vegetation, etc.) is much larger than the microscale roughness of the test plot, a separate area-wide roughness height reflecting the larger terrain features is used to convert the tunnel centerline wind speed to the equivalent wind speed at a standard 10-m height.

For test surfaces that are found to have a well-defined threshold velocity, sampling is initiated just after the tunnel centerline wind speed reaches the first prescribed super-threshold level corresponding to the desired friction velocity or wind speed corrected to a height of 10 m. Alternatively, for other test surfaces without a well-defined threshold velocity, sampling is initiated as air begins to flow through the wind tunnel. After the prescribed sampling period, the flow is shut off and the particulate samples (cyclone catch and glass fiber backup filter) are removed.

At the end of each test, the sampling train is disassembled and taken to the field instrument van, and the collected samples of dust emissions are carefully placed in protective containers. For transfer of samples to a laboratory setting, high-volume filters are placed in individual protective envelopes or in specially designed carrier cases. Dust is transferred from the cyclone precollector by brushing it into a tared clear, resealable plastic pouch. Alternatively, the cyclone catch can be sieved using a standard 325 sieve (45 μm pore size). The sieved cyclone catch, when recombined with the PM-10 mass from the backup filter, compromises total suspended particulate matter (TSP), which can be represented approximately as PM-30.

Dust samples from the field tests are returned to an environmentally controlled laboratory for gravimetric analysis. Glass fiber filters are conditioned at constant temperature (23°C ± 1°C) and relative humidity (45% ± 5%) for 24 h prior to weighing (the same conditioning procedure as used before tare weighing). The particulate catch from the cyclone precollector is weighed in the tared pouch.

The raw test data that are recorded include the following:

- Site code and description
- Test date, run number, and type of test
- Sample IDs (filters, cyclone catches, surface soils)
- Start time and sampling duration
- Threshold wind speed at tunnel centerline
- Subthreshold wind speed profile from which microscale roughness height is determined
- Operating wind speeds at tunnel centerline and at centerline of sampling tube

- Sampling module flow rate
- Ambient meteorology (wind speed and direction; temperature; barometric pressure)

## 2.3 Interpretation of Wind Tunnel Results

Because wind erosion is an avalanching process, it is reasonable to assume that the loss rate from the surface is proportional to the amount of erodible material remaining:

$$\frac{dM}{dt} = -kM \qquad (2)$$

where: M = quantity of erodible material present on the surface at any time, $g/m^2$
k = proportionality constant, $s^{-1}$
t = cumulative erosion time, s

Integration of Equation 2 yields:

$$M = Mo\ e^{-kt} \qquad (3)$$

where $M_o$ = erosion potential, i.e, quantity of erodible material present on the surface before the onset of erosion, $g/m^2$

The loss of erodible material ($g/m^2$) from the exposed surface area during a test is calculated as follows:

$$L = \frac{CQt}{A} \qquad (4)$$

where: C = average particulate concentration in tunnel exit stream (after subtraction of background concentration), $g/m^3$
Q = tunnel flow rate, $m^3/s$
A = exposed test surface area (0.918 $m^2$ for the reference wind tunnel 0.3716 $m^2$ for the reduced-scale wind tunnel)

Alternatively, the erosion potential can be directly calculated from the filter net mass (blank-corrected and with background subtracted).

Whenever a surface is tested at sequentially increasing wind speeds, the measured losses from the lower speeds are added to the losses at the next higher speed and so on. This reflects the hypothesis that, if the lower speeds had not been tested beforehand, correspondingly greater losses would have occurred at the higher speeds.

Emissions generated by wind erosion are dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action that results in the exposure of fresh surface material. On a soil surface, this would occur whenever soil is either added to or removed from the old surface, or whenever surface material is turned over to a depth exceeding the size of the largest pieces of aggregate present in the soil.

In summary, the calculated test results for each test surface and maximum wind speed include:

- Roughness height (microscale): from extrapolated subthreshold velocity profile
- Friction velocity: from measured centerline wind speed and roughness height, using Equation 1
- Equivalent wind speed at reference 10-m height: from measured centerline wind speed and roughness height, using Equation 1
- Erosion potential (for "limited reservoir" surfaces): equivalent to the cumulative particle mass loss at a particular wind speed

## 2.4 DustTRAK Monitoring

Continuous monitoring of particulate concentration in the emissions sampling module provides for a much greater level of detail in tracking the dynamics of the wind erosion process. In the case of the subject study, two portable DustTRAK Aerosol Monitors (TSI, Inc., St. Paul, Minnesota) continuously sampled air between the cyclone and the backup filter for the purpose of tracking the PM-10 and PM-2.5 concentrations in the tunnel effluent.

The DustTRAK monitor is a portable, battery-operated instrument that gives real-time measurements and has a built-in data logger. It weighs 3.3 lbs and uses four C cells. The instrument, as originally configured, samples PM-10, but can be fitted with a Dorr-Oliver nylon cyclone for industrial hygiene sampling (~3.5 μm cutpoint), or impactors for PM-2.5 and PM-1 sampling.

The operating principle of the DustTRAK is based on 90° light scattering. The theoretical detection efficiency based on Mie light scattering theory peaks at about 0.2-0.3 μm and gradually decreases for larger particle sizes. A pump draws aerosol into the optics chamber where either solid or liquid particles are detected. A laser diode light source, along with a solid-state photodetector, ensures greater stability and longevity. The specially designed sheath air system is used to isolate the aerosol in the chamber, keeping the optics clean and reducing maintenance. The instrument design gives measurements of particle concentrations from 0.001 to 200 mg/m$^3$. (Note that the instrument comes precalibrated to indicate mass concentration in mg/m$^3$ using Arizona road dust as the calibration reference).

The DustTRAK has two basic modes of operation: a survey mode and a logging mode. The survey mode displays real-time aerosol concentration measurements in $mg/m^3$. The logging mode functions similar to the survey mode with the added feature that the measurements are stored at programmable intervals for trending and reporting using the TrakPro Data Analysis Software.

Once data have been logged by the monitor (30,000 data points can be recorded using 3 logging modes), the DustTRAK software can retrieve the information for a more comprehensive analysis, including maxima, minima, and averages for the entire sampling period or any user-selected interval. The PC software also has a graphing capability that allows the comparison of PM-10 and PM-2.5 concentrations, assuming two monitors are available (one with a PM-2.5 impactor inlet) and simultaneous sampling occurs.

The DustTRAK PM-10 monitor is calibrated against the actual PM-10 mass collected on the back-up filter of the wind tunnel effluent sampling train during a given test run. This calibration entails an integration of the real-time DustTRAK PM-10 concentration profile (versus time) and calculation of the average DustTRAK PM-10 concentration for comparison to the average PM-10 concentration calculated from the net PM-10 mass collected on the back-up filter below the cyclone.

Use of the DustTRAK monitors provides for a more comprehensive analysis of surface erodibility, especially appropriate to the study of surfaces that do not have a well-defined wind erosion threshold velocity. On the burned vegetative surfaces at Rocky Flats, there are multiple contributors to wind generated particulate emissions: (a) the bulk soil with the usual protection afforded by consolidation, (b) settled surface dust that is trapped by the vegetation and resides on the soil surface, (c) settled dust that is trapped on the surface of the vegetation, and (d) the vegetation itself. The particle releases from these reservoirs are all driven by different mechanisms, each with a different wind speed dependence.

Thus, the approach taken in this study was (a) to expose each test surface of burned grassland to a well defined time history of increasing wind speeds, and (b) to monitor continuously the PM-10 and PM-2.5 concentrations in the tunnel effluent. Specifically, the tunnel centerline wind speed was increased in increments of 2 m/s (5 mph) up to the capacity of the wind tunnel as follows:

| Wind speed at tunnel CL (mph) | Start time (min:sec) | Duration (min:sec) |
|---|---|---|
| 5 | 0:00 | 2:00 |
| 10 | 2:00 | 2:00 |
| 15 | 4:00 | 2:00 |
| 20 | 6:00 | 4:00 |
| 25 | 10:00 | 4:00 |
| 30 | 14:00 | 4:00 |
| 35 | 18:00 | 4:00 |
| 40 | 22:00 | 4:00 |

Typically, each time the wind speed was increased, a PM-10 concentration spike was observed. Furthermore, upon each successive increase, the peak value of the spike increased and the rate of decay decreased. For centerline wind speeds at or above 20 mph, the duration of sampling was increased to a minimum of 4 min to allow additional time for the spike to decay. Time integration generates erosion mass increments that when added together yield cumulative erosion potentials for PM-10 and PM-2.5 as a function of wind speed.

## 2.5 Surface Soil Sampling

During the August testing, four subareas within the wildfire area near the wind tunnel test plot were selected for surface soil sampling. The areas were representative of the surfaces where MRI wind tunnel tests were performed. The surface soil samples were typical of the source material emitted from the wildfire-burned area through the wind erosion process.

Within each sampling area, approximately eight incremental samples were collected and then hand sieved into three size fractions: coarse, midsize and fine. The purpose of the size segregation of the surface soil sample was to determine whether higher isotopic activity was present in the fine soil fraction. A higher surface area to mass ratio for particles in the fine soil fraction could imply that radioactive contamination is preferentially attached to the fine soil particles.

Each incremental soil sample was hand sieved, using a nest of two sieves and a bottom pan. The coarse soil particles were collected on the top sieve, a standard sieve #30 with 600-micron openings. The mid-size soil fraction passed through sieve #30 but was captured on a standard sieve #200 with 75-micron openings. Finally, the fine (silt) fraction passed the standard sieve #200 and was captured in the bottom pan. Before the incremental surface soil samples were sieved, the larger pebbles and larger pieces of organic material (dead and burnt grass, occasionally deer droppings) were manually retrieved and discarded.

The sieving was accomplished by manually rotating and tapping the covered nest of sieves at the sampling location. Forty rotations were performed for each dry surface sample, and the sieves were tapped by hand after each ten rotations, for a total of 4 taps. After hand sieving, each size fraction was transferred to a labeled sample bottle. This method is very similar to the hand-sieving procedure found in AP-42, EPA's *Compilation of Air Pollutant Emission Factors.*

A method was developed to collect approximately equal amounts of three 125-mL samples from each soil sample, one for each of three size fractions. First, all the sieved silt from the pan was transferred to the 125-mL bottle designated for the fine soil fraction. Second, an equal volume of the mid-size soil fraction was transferred to the mid-size bottle. Third, an equal volume of the coarse soil fraction was transferred to the coarse soil bottle, after removal of most of the thatch that had accumulated on the top sieve (#30). In summary, six to eight surface soil samples, each of approximately 200 to 300 g, were required from each of the four wildfire areas to obtain 125-mL volumes for the three sieve fractions.

## 2.6 Isotopic Analysis of PM-10 Filters and Soil Samples

The procedures for isotopic analysis of PM-10 on filters and in soil samples are discussed in the Sampling and Analysis Plan.

# Section 3.
# Results of Field Tests

The field tests were conducted on August 22-25, 2000. Wind tunnel tests were performed (a) on an unpaved road (raked gravel surface) using both the MRI reference wind tunnel and the reduced-scale wind tunnel, and (b) on the wildfire area using the reduced-scale wind tunnel.

## 3.1 Tunnel Comparison Tests on Unpaved Road

On August 22, 2000, wind tunnel tests were performed on an unpaved roadway in the Rocky Flats area, so that the performance of the reference wind tunnel and the reduced-scale wind tunnel could be compared. The test roadway had a uniformly textured surface material (i.e., raked aggregate). A total of five wind tunnel tests were performed, three using the reduced-scale wind tunnel and two with the reference wind tunnel. The first two tests, Runs CB-16A and CB-16B incorporated the same cyclone back-up filter to provide more sample mass for gravimetric measurement.

The wind tunnel tests were performed at incrementally increasing tunnel centerline wind speeds. The wind speed increments were 2 m/s (5 mph) at the centerline, up to the capacity of the wind tunnel. The "peak" PM-10 and PM-2.5 concentration values (6-sec averages) for each wind speed plateau was observable in the "real-time" concentration histories, recorded by the DustTRAK monitors.

The test site parameters are presented in Table 1. The reduced-scale wind tunnel was used for Runs CB-16 and CB-19, and the larger reference tunnel was employed on Runs CB-17 and CB-18. The surface roughness height of the gravel surface was found using the reference wind tunnel velocity profiles from Runs CB-17 and CB-18.

The comparison tests on the unpaved road surface indicate that the reference wind tunnel and the reduced-scale wind tunnel measured similar values for PM-10 concentration and TP erosion potential, neither of which are affected by nonisokinetic sampling. The PM-10 erosion potentials and the TP concentrations differed between the two tunnels, due to anisokinetic sampling that occurred when the sampling extension for the high-flow reference wind tunnel was adapted to the reduced-scale wind tunnel. This resulted in a superisokinetic condition because of the reduced flow rate in the sampling extension. The superisokinetic sampling condition oversamples PM-10 mass and underestimates the TP concentration. The procedure for adjusting for this sampling situation begins with determining the isokinetic flow ratio (IFR), which is defined as the ratio of sampling intake velocity to approach flow velocity. Then the TP concentration is multiplied by the IFR and the PM-10 mass collected is divided by the IFR.

Table 2 presents the average concentration values observed during the wind tunnel tests. The IFR corresponding to the maximum 10-m wind speed is also provided. In Table 2, the TP concentration in the reduced-scale wind tunnel effluent has been adjusted for anisokinetic sampling as previously described. The average concentrations produced during all four tests are approximately equivalent, i.e., within the range of variation normally encountered in wind tunnel tests of subareas of the same surface type. Thus, no correction is needed for concentration results from the reduced-scale wind tunnel.

Table 3 presents the erosion potential values for the gravel road surface, with the reduced-scale wind tunnel values adjusted for anisokinetic sampling. The values are again roughly equivalent between the two wind tunnels, showing that a correction for the erosion potential values provided by the smaller wind tunnel is not necessary. Since the calculated erosion potentials apply to different 10-m wind speeds attained during testing, the values were adjusted to a 50-mph wind speed to provide for a better comparison. As an illustration of the effects of adjusting for anisokinetic sampling, the adjustment lowered the average loss ratio for the reduced-scale wind tunnel tests from 0.175 to 0.041, which is close to the average value of 0.053 for the tests performed with the reference wind tunnel.

## 3.2 Wildfire Tests

Field tests of the wildfire area were performed from August 23-25, 2000, using the reduced-scale MRI wind tunnel. During each test, the wind tunnel was moved six times to separate test plots within the wildfire area, to increase the particulate sample masses and improve the detection of actinide activity and the PM-10 erosion potential.

The wind tunnel tests were performed at incrementally increasing tunnel centerline wind speeds. The wind speed increments were 2 m/s (5 mph) at the centerline, up to the capacity of the wind tunnel as done in the unpaved road tests. The "peak" PM-10 and PM-2.5 concentration values (6-sec averages) for each wind speed plateau were observable in the "real-time" concentration histories, recorded by the DustTRAK monitors.

The test site parameters for each of the wind tunnel test runs in the wildfire area are provided in Table 4. The surface roughness height was determined for only one test due to the difficulty in positioning the pitot tube at specified distances from the ground surface. The surface roughness height was determined from the wind speed profile for Run CB-23F. The vertical profile of wind speed in the test section of the wind tunnel was fitted to a logarithmic function to determine a surface roughness height that is considered representative for the wildfire-burned area.

**Table 1. Test Site Parameters for Comparative Wind Tunnel Tests (8/22/00)**

| Run no. | Surface characteristics | Wind tunnel | Start time | Duration (min) | Wind speed(mph)/ direction | Temperature (°F) | Barometric Pressure (in. Hg) | Relative humidity (%) | Surface roughness height (cm) |
|---|---|---|---|---|---|---|---|---|---|
| CB-16A | Unpaved Road | Reduced-scale | 10:40 | 19 | 7 NE | 86 | 24.50 | 30 | NA |
| CB-16B | | | 11:50 | 19 | 7 NE | 86 | 24.50 | 30 | NA |
| CB-17 | Unpaved Road | Reference | 14:05 | 30 | 5.4 SSE | 82 | 24.50 | 28 | 0.02 |
| CB-18 | Unpaved Road | Reference | 15:06 | 25 | 2.8 | 83 | 24.50 | 26 | 0.04 |
| CB-19 | Unpaved Road | Reduced-scale | 16:09 | 17 | 8.1 NNE | 81 | 24.50 | 31 | NA |

NA= no data available

**Table 2. Comparative Wind Tunnel Test Results: Average Concentrations**

| Run no. | Duration (min) | Average effluent PM-10 conc. ($mg/m^3$) | Background PM-10 conc.[b] ($mg/m^3$) | Net[a] effluent PM-10 conc. ($mg/m^3$) | Maximum wind speed IFR | Net[a] effluent TP Conc.[c] ($mg/m^3$) | Average DustTRAK PM-10 conc. ($mg/m^3$) | Ratio of effluent/ DustTRAK PM-10 conc. | Average DustTRAK PM-2.5 conc. ($mg/m^3$) | Ratio of DustTRAK PM-2.5 conc./ PM-10 conc. |
|---|---|---|---|---|---|---|---|---|---|---|
| CB-16 | 38 | 7.03 | 0.019 | 7.01 | 4.89 | 165.80 | 0.513 | 13.71 | 0.349 | 0.68 |
| CB-17 | 30 | 6.00 | 0.019 | 5.98 | 0.95 | 109.82 | 0.779 | 7.70 | 0.467 | 0.60 |
| CB-18 | 25 | 7.57 | 0.019 | 7.55 | 1.07 | 146.30 | 0.997 | 7.59 | 0.478 | 0.48 |
| CB-19 | 17 | 3.04 | 0.019 | 3.02 | 4.98 | 74.50 | 0.366 | 8.29 | 0.166 | 0.45 |

[a] Net = Average effluent concentration - Background concentration
[b] Historical Rocky Flats PM-10/TSP ratio of 0.3895 used.
[c] Reduced scale wind tunnel values adjusted for anisokinetic sampling.

**Table 3. Comparative Wind Tunnel Test Results: Erosion Potentials**

| Run no. | Roughness height[a] (cm) | Tunnel centerline (CL) height (cm) | Maximum wind speed (mph) at tunnel CL | Equivalent maximum wind speed (mph) at 10-m height | Corresponding friction velocity (cm/s) | Erosion potential/loss[b] ($g/m^2$) | | | Erosion potential/loss at a 50 mph wind speed at 10-m height ($g/m^2$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | TP[c] | PM-10[c] | Loss ratio (PM-10/TP) | TP[c] | PM-10[c] | Loss ratio (PM-10/TP) |
| CB-16 | 0.03 | 7.65 | 29.6 | 55.6 | 95.4 | 133.5 | 5.6 | 0.042 | 120.1 | 5.0 | 0.042 |
| CB-17 | 0.02 | 15.2 | 37.4 | 62.6 | 107.4 | 276.6 | 15.1 | 0.054 | 221.1 | 12.0 | 0.054 |
| CB-18 | 0.04 | 15.2 | 36.7 | 61.4 | 105.5 | 307.1 | 15.8 | 0.052 | 249.9 | 12.9 | 0.052 |
| CB-19 | 0.03 | 7.65 | 25.4 | 47.8 | 82.1 | 52.6 | 2.1 | 0.040 | 55.0 | 2.2 | 0.040 |

[a]Roughness height not calculated for smaller wind tunnel runs, average of two larger runs used.
[b]Erosion potential calculated using net mass and alternative calculation.
[c] Reduced scale wind tunnel values adjusted for anisokinetic sampling.

## Table 4. Test Site Parameters for Wildfire Tests

| Date | Surface characteristics | Run no. | Start time | Duration (min) | Wind speed (mph)/ direction | Temperature (°F) | Barometric pressure (in. Hg) | Relative humidity (%) |
|---|---|---|---|---|---|---|---|---|
| 8/23/00 | Wildfire Area | CB-20A | 11:33 | 21 | 8.5 | 79 | 24.75 | 43 |
| | | CB-20B | 12:04 | 22 | 7.2 S | 85 | NA | 35 |
| | | CB-20C | 12:34 | 22 | 4.1 SSE | 85 | NA | 32 |
| | | CB-20D | 13:13 | 20 | 6.5 SE | 85 | 24.70 | 33 |
| | | CB-20E | 13:42 | 24 | 7.5 SE | 86 | NA | 29 |
| | | CB-20F | 14:28 | 21 | 8.0 ESE | 85 | NA | 31 |
| 8/24/00 | Wildfire Area | CB-21A | 8:22 | 22 | NA | NA | 24.70 | NA |
| | | CB-21B | 8:51 | 21 | 1.9 SE | 76 | NA | 33 |
| | | CB-21C | 9:20 | 22 | 3.5 E | 76 | NA | NA |
| | | CB-21D | 9:53 | 22 | NA | NA | NA | NA |
| | | CB-21E | 10:22 | 27 | NA | NA | NA | NA |
| | | CB-21F | 10:55 | 30 | 3.2 SE/E | 82 | 24.80 | 33 |
| 8/24/00 | Wildfire Area | CB-22A | 12:57 | 20 | 4.6 SSE | 82 | 24.80 | 28 |
| | | CB-22B | 13:23 | 21 | 6 | 84 | NA | 29 |
| | | CB-22C | 13:59 | 21 | 6.4 S | 82 | NA | 28 |
| | | CB-22D | 14:25 | 22 | 4.5 S | 83 | 24.70 | 31 |
| | | CB-22E | 14:52 | 21 | 3.1 SW | NA | NA | NA |
| | | CB-22F | 15:19 | 21 | 3.6 S/SSW | 90 | NA | 25 |
| 8/25/00 | Wildfire Area | CB-23A | 8:06 | 21 | 3.4 N | 75 | NA | 47 |
| | | CB-23B | 8:34 | 21 | 1.7 | 76 | 24.70 | 37 |
| | | CB-23C | 8:59 | 31 | 1 | 78 | NA | 38 |
| | | CB-23D | 9:30 | 22 | 4.3 E | 83 | NA | 35 |
| | | CB-23E | 9:57 | 21 | 4.6 E | 84 | NA | 28 |
| | | CB-23F | 10:24 | 21 | 5.8 E | 82 | 24.70 | 29 |

NA= no data available.

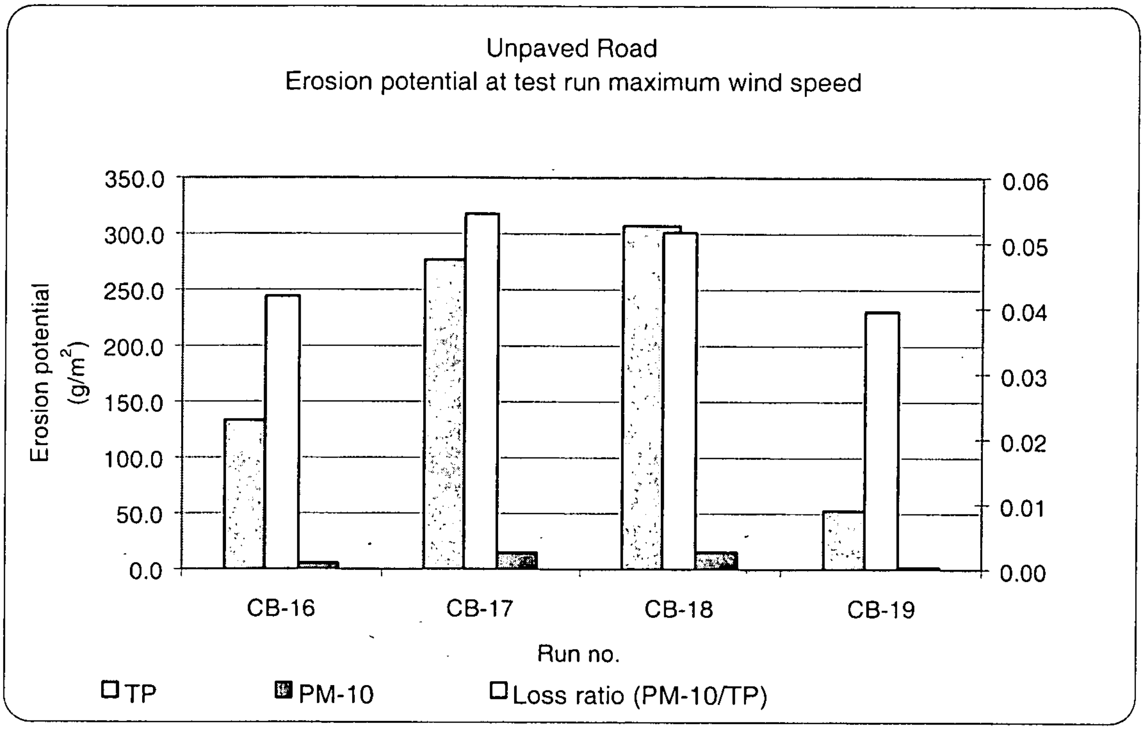


**Figure 2. Erosion Potentials at Test Run Maximum Wind Speed for Comparative Wind Tunnel Tests on Unpaved Road**

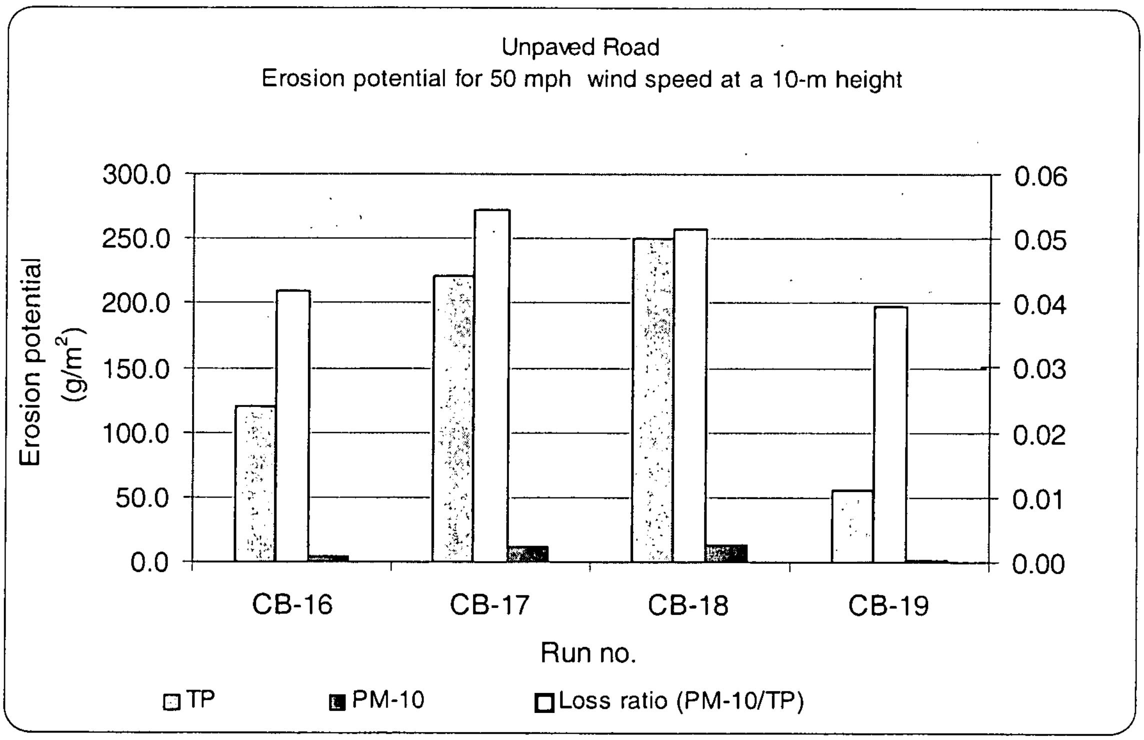


**Figure 3. Erosion Potentials for 50 Mph Wind Speed at 10-M Height for Comparative Wind Tunnel Tests on Unpaved Road**

The average concentrations for the wind tunnel tests of the wildfire area are presented in Table 5. The same procedure used for the unpaved road comparison tests to adjust the TP concentration and PM-10 mass was also incorporated in the wildfire area calculations. Since the mass collected on the background filter constitutes TSP, the background air concentrations of PM-10 were determined using the average PM-10/TSP ratio of 0.39 from historical air quality data at Rocky Flats. The relatively high background concentration found on Run CB-23 required adjustment based on the highest proportion of inlet outlet concentration of 0.06. The high background concentration determined from the filter mass was probably due to the recirculation of the effluent from the wind tunnel.

At the time, it was not known if sufficient mass could be generated from an undisturbed wildfire surface, so for Runs CB-20 and CB-21, the surface was raked to insure release of adequate soil emissions for characterization of actinide activity in the PM-10 fraction. After preliminary analysis of sample masses collected in Runs CB-20 and CB-21, Runs CB-22 and CB-23 were conducted on an undisturbed wildfire surface. These last two tests best represent the soil erosion process for the wildfire burned area.

Table 5 shows that the average PM-10 concentration in the tunnel effluent, as determined from the filter mass loading, was several times higher than the average PM-10 concentration indicated by the DustTRAK. This reflects the fact that while the coarse mode of the PM-10 (particles larger than 2.5 µm but smaller than 10 µm) constitutes much of the PM-10 sample mass, it does not scatter light very effectively. This behavior also tends to inflate the PM-2.5/PM-10 ratio given in the last column of Table 5.

Table 6 presents calculated values of PM-10 and TSP erosion potential for each test run. The PM-10 erosion potentials are shown graphically in Figure 4. Consistent with the unpaved road tests, the reduced-scale wind tunnel generated an inflated proportion of PM-10 to TSP eroded from the surface, due to anisokinecity and oversampling of PM-10 mass. Adjusting the PM-10 mass by the IFR produced more reasonable values for the erosion potential and PM-10/TSP loss ratio.

The 6-sec DustTRAK average PM-10 concentration values for each of the test runs were used to find an average time-integrated concentration value from the beginning of the test run to the end of the incremental test period (for each 10-m wind speed plateau). The average concentration, together with the tunnel volumetric flow rate, the length of time from the beginning of the test until the end of the incremental test period, and the exposed test surface area were used to determine the PM-10 erosion potential for each 10-m wind speed. Because the surface tested in Runs CB-20 and CB-21 was artificially disturbed by raking before testing, the incremental erosion potentials were calculated only for the undisturbed surfaces that were tested in Runs CB-22 and CB-23. The average PM-10 erosion potential values for Runs CB-22 and 23 are given in Table 7.

**Table 5. Average Concentrations for Wildfire Area**

| Date | Run No. | Duration (min) | Average effluent TSP conc.[e] ($mg/m^3$) | Background TSP conc. ($mg/m^3$) | Net TSP conc.[b] ($mg/m^3$) | Average effluent PM-10 conc. ($mg/m^3$) | Background PM-10 conc.[a] ($mg/m^3$) | Net PM-10 conc.[b] ($mg/m^3$) | Average DustTRAK PM-10 conc.[c] ($mg/m^3$) | Ratio of effluent PM-10/ DustTRAK PM-10 conc. | Average DustTRAK PM-2.5 conc.[c] ($mg/m^3$) | Ratio of DustTRAK PM-2.5 conc./ PM-10 conc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/23/00 | CB-20 | 130 | 10.541 | 0.677 | 9.864 | 1.595 | 0.264 | 1.332 | 0.172 | 9.26 | 0.063 | 0.36 |
| 8/24/00 | CB-21 | 144 | 7.198 | 0.052 | 7.146 | 2.847 | 0.020 | 2.827 | 0.047 | 60.15 | 0.016 | 0.34 |
| 8/24/00 | CB-22 | 126 | 1.980 | 0.052 | 1.928 | 0.508 | 0.020 | 0.488 | 0.060 | 8.43 | 0.026 | 0.43 |
| 8/25/00 | CB-23 | 137 | 0.572 | 0.239 | 0.333 | 0.239 | 0.093 | 0.146 | 0.032 | 7.58 | 0.015 | 0.47 |
| | CB-23[d] | 137 | 0.572 | 0.034 | 0.538 | 0.239 | 0.013 | 0.226 | 0.032 | 7.58 | 0.015 | 0.47 |

[a] Background PM-10 mass determined by using Rocky Flats PM-10/TSP ratio of 38.95%.
[b] Net = Average effluent concentration – Background concentration.
[c] DustTRAK averages determined by finding mean concentration over all six tests.
[d] CB-23 background concentration adjusted to be 6% of effluent concentration (largest ratio of other three tests).
[e] TSP concentration adjusted for anisokinetic sampling.

NOTE: all emission sampler values corrected for average blank filter weights.

**Table 6. Erosion Potentials for Wildfire Area**

| | | | | | | | Erosion potential/loss ($g/m^2$) | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Run No. | Average roughness height[a] (cm) | Maximum wind speed (mph) at tunnel CL | Equivalent maximum wind speed (mph) at 10-m height[b] | Corresponding friction velocity[b] (cm/s) | Maximum wind speed IFR | TSP[e] | PM-10[e] | Loss ratio (PM-10/TSP) |
| 8/23/00 | CB-20 | 1.21 | 23.9 | 87.2 | 232.2 | 5.37 | 5.78 | 0.15 | 0.03 |
| 8/24/00 | CB-21 | 1.21 | 27.5 | 100.3 | 267.0 | 4.66 | 7.43 | 2.94 | 0.40 |
| 8/24/00 | CB-22 | 1.21 | 26.5 | 96.6 | 257.1 | 4.93 | 1.52 | 0.36 | 0.24 |
| 8/25/00 | CB-23 | 1.21 | 26.5 | 96.5 | 256.9 | 4.58 | –0.54 | –0.19 | 0.36 |
| | CB-23[d] | 1.21 | 26.5 | 96.5 | 256.9 | 4.58 | 0.43 | 0.18 | 0.43 |

[a] Roughness height determined from CB-23F used for all tests.
[b] Average maximum wind speed at tunnel centerline (CL) for all six tests.
[c] Calculated using net mass, ratio of sampling tube area to nozzle area, and exposed test surface area.
[d] CB-23 background concentration adjusted to be 6% of effluent concentration.
[e] Erosion potentials adjusted of anisokinetic sampling.

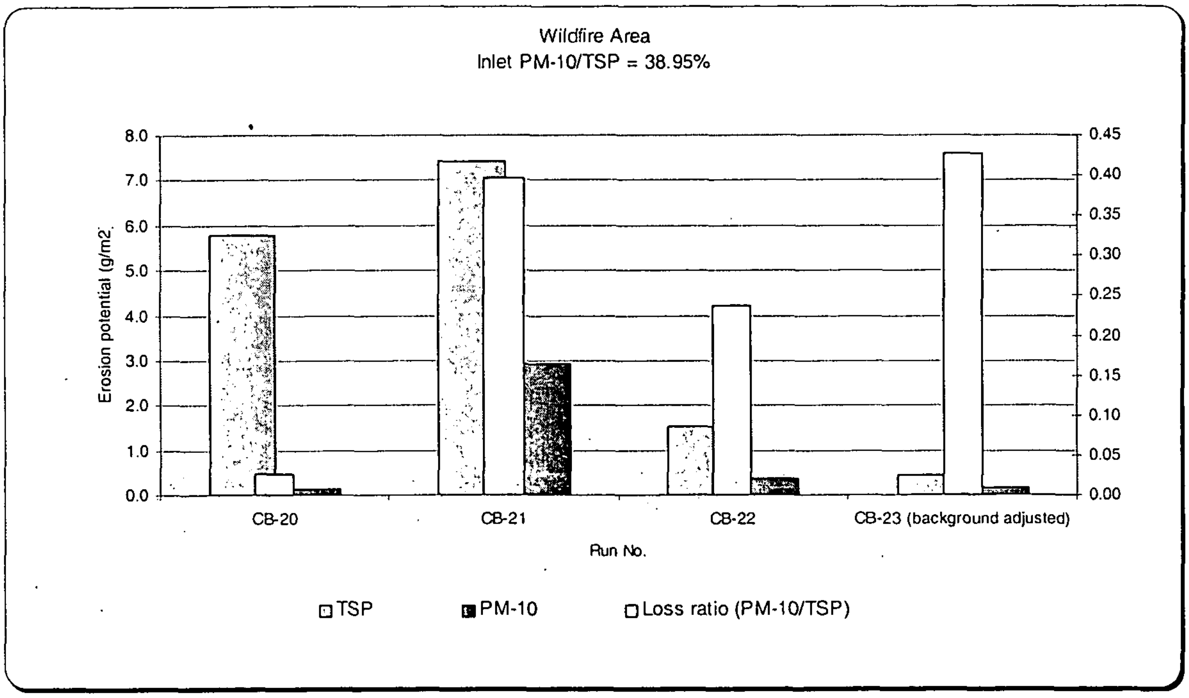


**Figure 4. Erosion Potential History**

**Table 7. DustTRAK Average PM-10 Erosion Potentials vs. 10-m Wind Speed**

| Wind speed (mph) at 10-m height | DustTRAK ($g/m^2$) | | | Mass-weighted based on emission sampler DustTRAK PM-10 conc. ratio ($g/m^2$) | | |
|---|---|---|---|---|---|---|
| | CB-22 | CB-23 | Undisturbed areas average | CB-22 | CB-23 | Undisturbed areas average |
| 13 | 0.0002 | 0.0001 | 0.0002 | 0.002 | 0.001 | 0.001 |
| 27 | 0.0016 | 0.0005 | 0.0011 | 0.013 | 0.004 | 0.009 |
| 40 | 0.0050 | 0.0015 | 0.0034 | 0.040 | 0.012 | 0.026 |
| 53 | 0.0128 | 0.0043 | 0.0089 | 0.102 | 0.035 | 0.068 |
| 67 | 0.0281 | 0.0104 | 0.0215 | 0.225 | 0.084 | 0.154 |

Figure 5 shows the average PM-10 erosion potential versus 10-m wind speed (mph) as determined from DustTRAK data. Because the optically read DustTRAK PM-10 concentrations were consistently lower than PM-10 concentrations from mass-based samplers, mass weighting was performed by finding the average concentration during the period of testing for both the DustTRAK and the emission sampler. The ratio of these two concentrations allowed for conversion of the DustTRAK erosion potentials to the actual erosion potentials shown in Figure 5.

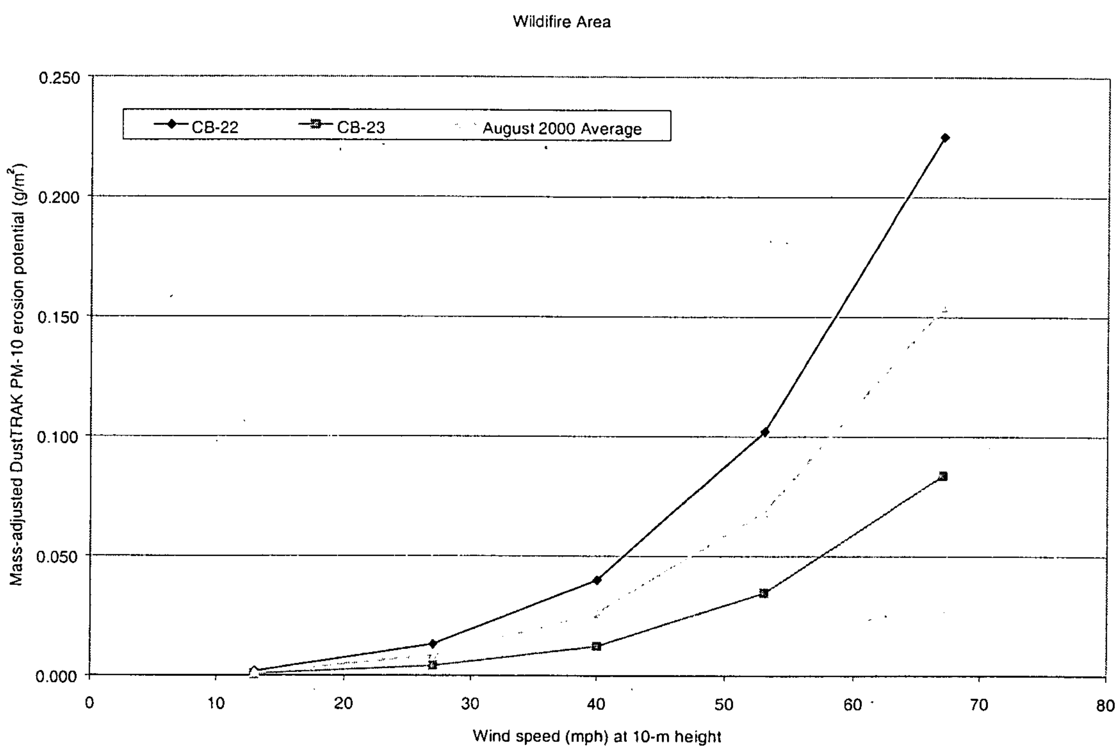


**Figure 5. Erosion Potential at 10-m Wind Speeds as Determined by Emission Sampler Weighted DustTRAK Data**

# Section 4.
# Results of Laboratory Tests

## 4.1 Isotopic Analyses of Soil Samples

Isotopic analyses of the 12 soil samples (4 wildfire plots x 3 size fractions) were also performed. As shown in Table 8, the four coarse soil fractions contained the minimum isotopic activity levels for Pu239, with an average 1.27 pCi/g. This may have resulted from a higher proportion of organic material (small pieces of thatch) in this largest size fraction. The two finer size fractions exhibited approximately equal activity rates of 2.09 pCi/g for the mid-size fraction, and 1.77 pCi/g for the silt (fine) fraction.

A 125-mL volume of each of the three sieve fractions of surface soil (> 600 microns; 75-600 microns; < 75 microns) was obtained from four wildfire plots for isotopic analysis. As shown in Table 8, over 90 percent of the surface soil in the wildfire area was in the coarse (average 50 percent) and mid-size (42 percent) ranges, with only 8 percent of the surface soil in the silt size range (e.g., less than 75 micron diameter). Thus, the 125-mL sample volumes were easiest to obtain for the two largest size fractions, but sieving of multiple samples was required to obtain a 125-mL sample of the silt fraction.

**Table 8. Pu239 Activity by Soil Particle Size for Wildfire Surface Soil Samples**

| Sample ID | Location | Size fraction | Pu239 (pCi/g) | Mass fraction of loose soil[1] | Average Pu239 (pCi/g) | Average mass fraction of loose soil | Average portion of Pu239 total activity |
|---|---|---|---|---|---|---|---|
| 003.001 | 1 | Coarse | 1.03 | 49.7% | **1.27** | **49.7%** | **37.6%** |
| 006.001 | 2 | Coarse | 0.85 | 53.2% | | | |
| 009.001 | 3 | Coarse | 1.78 | 46.5% | | | |
| 012.001 | 4 | Coarse | 1.43 | 49.4% | | | |
| 002.001 | 1 | Mid | 2.23 | 42.0% | **2.09** | **42.0%** | **53.7%** |
| 005.001 | 2 | Mid | 1.54 | 39.6% | | | |
| 008.001 | 3 | Mid | 2.20 | 43.3% | | | |
| 011.001 | 4 | Mid | 2.40 | 43.0% | | | |
| 001.001 | 1 | Fine | 2.09 | 8.2% | **1.77** | **8.2%** | **8.8%** |
| 004.001 | 2 | Fine | 0.94 | 7.2% | | | |
| 007.001 | 3 | Fine | 2.37 | 10.1% | | | |
| 010.001 | 4 | Fine | 1.66 | 7.4% | | | |

[1] For locations 2-4, mass of each size fraction was determined for one soil sample of the several composited. For location 1, the averages of location 2-4 size ratios were used; no size ratio measurements were performed.

## 4.2 Isotopic Analysis of PM-10 Filter Samples

The fine soil fraction (< 75 μm) is the source of all PM-10 emissions from wind erosion. Thus, the Pu239 activity level associated with the fine soil fraction (1.77 pCi/g) can be compared to the activity level of the particulate mass of PM-10 captured on the filter. The comparison is presented in Table 9a, and shows an average activity level of 1.19 pCi/g for PM-10 mass captured on the 8-in x 10-in backup filter. The PM-10 activity level is higher (1.19 and 1.85 pCi/g) for the two artificially disturbed test areas (runs CB-20 and CB-21), than for the undisturbed soil (1.08 and 0.66 pCi/g).

This reduced Pu239 activity on the undisturbed soil may indicate that the uppermost thin layer of surface soil is less contaminated with Pu239 than the surface soil profile extending to a depth of 1 to 2 cm below the surface. This might be attributed to surface deposition of uncontaminated particles from ambient air. Certainly, an area with standing vegetation, such as the unburned grassland at Rocky Flats, will tend to trap airborne fine particles that are deposited on the vegetation and on the soil surface. Precipitation will tend to transfer the particles collected on the vegetation to the soil below. Thus, a less contaminated crust of fine particles (assuming rainfall does not wash away most deposited particles) will be formed on the soil surface and will protect against wind erosion emissions. Any emissions that do occur will contain lower concentrations of Pu239 than found in disturbed surfaces with exposed lower soil profiles.

Ambient background concentrations were measured during the four wildfire tests of wind erosion. Because runs CB-21 and CB-22 were performed on the same day, only one background sample was required. Background Pu239 activity levels for PM-10 and TSP are shown in Tables 9a and 9b. Clearly, the Pu239 activity in background PM-10 is very low in comparison with PM-10 generated from the surface soil at the wildfire area. As stated above, a thin surface layer of soil deposited from ambient air will contain little Pu239, and, if crusted, can serve to protect the underlying contaminated soil from wind erosion of Pu239-contaminated particles lying below the surface.

The net PM-10 and TSP concentrations along with the respective Pu239 concentrations are presented in Table 10.

## Table 9a. Wind Tunnel Test Data for Isotopic Analysis of PM-10 Samples

| Run | Emission sampling duration (min) | Background sampling duration (min) | Tunnel effluent mass[a] (mg) | Tunnel inlet mass[a,b] (mg) | Tunnel effluent conc. (mg/m³) | Tunnel inlet conc. (mg/m³) | Tunnel effluent Pu239 activity (dpm) | Tunnel inlet Pu239 activity (dpm) | Tunnel effluent Pu239 activity (pCi/g) | Tunnel inlet Pu239 activity (pCi/g) | Tunnel effluent Pu239 conc. (pCi/m³) | Tunnel inlet Pu239 conc. (pCi/m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CB-20 | 130 | 138 | 234.87 | 41.20 | 1.595 | 0.264 | 0.621 | 0.463 | 1.19 | 1.97 | 0.00190 | 0.0005191 |
| CB-21 | 144 | 289 | 464.37 | 6.69 | 2.847 | 0.020 | 1.910 | 0.004 | 1.85 | 0.10 | 0.00527 | 0.0000021 |
| CB-22 | 126 | 289 | 72.57 | 6.69 | 0.508 | 0.020 | 0.174 | 0.004 | 1.08 | 0.10 | 0.00055 | 0.0000021 |
| CB-23 | 137 | 133 | 37.07 | 14.05 | 0.239 | 0.093 | 0.054 | 0.061 | 0.66 | 0.76 | 0.00016 | 0.0000710 |
| CB-23[c] | 137 | 133 | 37.07 | 2.01 | 0.239 | 0.013 | 0.054 | 0.009[d] | 0.66 | 0.76 | 0.00016 | 0.0000102 |

NOTE: Background ≡ Tunnel inlet.

[a] PM-10 net mass on filter is corrected for average of seven filter blank weights (-1.4 mg).

[b] Tunnel inlet PM-10 mass =38.95% TSP mass collected on filter.

[c] CB-23 background adjusted.

[d] Activity level adjusted based on actual activity level per mass.

## Table 9b. Wind Tunnel Test Data for Isotopic Analysis of TSP Samples

| Run | Emission sampling duration (min) | Background sampling duration (min) | Tunnel effluent PM-10 mass[a] (mg) | Tunnel effluent >PM-10 mass[c] (mg) | Tunnel effluent TSP mass (mg) | Tunnel inlet TSP mass[a] (mg) | Tunnel effluent TSP conc.[c] (mg/m³) | Tunnel inlet TSP conc. (mg/m³) | Tunnel effluent PM-10 Pu239 activity (dpm) | Tunnel effluent >PM-10 Pu239 activity (pCi/g) | Tunnel inlet TSP Pu239 activity (dpm) | Tunnel effluent TSP Pu239 activity (pCi/g) | Tunnel inlet TSP Pu239 activity (pCi/g) | Tunnel effluent TSP Pu239 conc. (pCi/m³) | Tunnel inlet TSP Pu239 conc. (pCi/m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CB-20 | 130 | 138 | 234.87 | 1317.26 | 1552.13 | 105.77 | 10.541 | 0.677 | 0.621 | 2.140 | 0.463 | 1.675 | 1.970 | 0.0210 | 0.001333 |
| CB-21 | 144 | 289 | 464.37 | 709.72 | 1774.09 | 17.17 | 7.981 | 0.052 | 1.910 | 1.930 | 0.004 | 1.870 | 0.105 | 0.0137 | 0.000005 |
| CB-22 | 126 | 289 | 72.57 | 210.07 | 282.59 | 17.17 | 1.980 | 0.052 | 0.174 | 1.200 | 0.004 | 1.124 | 0.105 | 0.0023 | 0.000005 |
| CB-23 | 137 | 133 | 37.07 | 51.75 | 88.83 | 36.07 | 0.572 | 0.239 | 0.054 | 2.430 | 0.061 | 1.070 | 0.761 | 0.0010 | 0.000182 |
| CB-23[b] | 137 | 133 | 37.07 | 51.75 | 88.83 | 5.17 | 0.572 | 0.034 | 0.054 | 2.430 | 0.016 | 1.070 | 0.761 | 0.0010 | 0.000026 |

[a] Net mass on filter is corrected for average of seven filter blank weights (–1.4 mg).

[b] CB-23 background adjusted.

[c] Adjusted for anisokinetic sampling.

**Table 10. Summary of PM-10 and TSP Pu239 Unit Activity and Concentrations**

| Run | Net PM-10 emission conc. (mg/m³) | Pu239 concentration in eroded PM-10 (pCi/m³) | Net TSP emission conc. (mg/m³) | Pu239 concentration in eroded TSP (pCi/m³) |
|---|---|---|---|---|
| CB-20 | 1.332 | 0.00138 | 9.864 | 0.0197 |
| CB-21 | 2.827 | 0.00527 | 7.146 | 0.0137 |
| CB-22 | 0.488 | 0.00055 | 1.928 | 0.0023 |
| CB-23 | 0.146 | 0.00009 | 0.333 | 0.0008 |
| CB-23[a] | 0.215 | 0.00014 | 0.538 | 0.0009 |

[a] CB-23 background adjusted.

## 4.3 Soil Deposition

After stabilization of the Pu239 source area, relatively clean ambient air particles will be deposited to the ground through both dry and wet deposition. Some of these particles will initially be intercepted by vegetation and then either washed off to the ground or resuspended by the wind. If the ground is covered with grasses, vegetative thatch, or other non-erodible elements, little resuspension of ground based particles will occur. This was demonstrated in the two sets of wind erosion tests on unburned areas at Rocky Flats in April and June 2000. Consequently, particle deposition will likely exceed particle resuspension for well-vegetated areas.

In semi-arid regions such as Rocky Flats, little water runoff of soil occurs, so that soil continues to accumulate in vegetated areas. The particle deposition rate is a measure of particles deposited from the air to a unit area of ground per year. The deposition rate is obtained by multiplying the particle mass concentration at a height of approximately 1 m by the deposition velocity (default value of 1000 m/day). This deposition rate reflects both wet and dry particle deposition to the ground.

A reasonable approximation of the ambient air PM-10 concentration at Rocky Flats is 20 $\mu g/m^3$. Based on many studies of PM-10, a considerable fraction of these particles is organic in nature. Carbon particles will not contribute to long-term soil buildup as they are released to the air and to vegetative uptake. For calculation purposes, a conservatively low 10 $\mu g/m^3$ PM concentration is assumed to produce an annual deposition rate of 3.65 $kg/m^2/yr$. Assuming half of this amount is washed off by rainfall, the annual soil buildup rate is 1.8 $kg/m^2/yr$, or 0.08 cm/yr.

This soil buildup will consist of relatively clean particles. As shown in Table 9a, the Pu239 activity rates in background air were found to be very low—ranging from 0.0001 to 0.0020 pCi/g. The highest value of 0.0020 pCi/g occurred during variable winds that may have transported eroded particles from the outlet of the tunnel blower to the background sampler.

# Section 5.
# Conclusions

The comparison tests between the reference wind tunnel and the reduced-scale wind tunnel on the unpaved road surface showed that the two tunnels produce erosion test results that are equivalent, i.e., within the range of variation normally found between test areas of the same type. Although the reduced-scale wind tunnel samples under anisokinetic conditions, the correction using the IFR was found to be the only adjustment needed to provide a good comparison between tests performed using the reference wind tunnel and the reduced-scale wind tunnel.

Only 8 percent of the surface soil at the wildfire areas is in the particle size range that can be suspended as dust emissions (i.e., silt particles with diameters less than 75 µm). A significant fraction of Rocky Flats soil particles in the wildfire area were found to be protective of wind erosion emissions because of their size. Nearly 50 percent of the soil particles in the wildfire area are greater than 600 µm. The burned vegetative stubble provided additional protection against wind erosion.

In addition, the coarsest soil size range above 600 µm in diameter was found to have the lowest Pu239 activity (1.27 pCi/g). The highest Pu239 activity (2.09 pCi/g) was observed in the mid-size range (75-600 µm diameter). The silt soil fraction (< 75 µm diameter) had a Pu239 activity level of 1.77 pCi/g, which is also representative to the composite soil activity level. The observation was counter to the hypothesis that the finest soil particles on the surface were most contaminated with Pu239.

When the soil was disturbed to a depth of 1 to 2 cm, wind tunnel tests of the wildfire area showed both higher erodibility and higher Pu239 activity rate than for the undisturbed wildfire soil. This indicates that the surface soil is less contaminated than the soil immediately beneath the surface. This may be attributed to dry and wet soil deposition of "cleaner" ambient air particles that accumulate on the soil surface over time. The deposition rate would result in a relatively clean (but thin) soil surface layer that, if crusted, would inhibit wind erosion of subsurface contaminated soil.

# Section 6. References


Baxter, T. E., D. D. Lane, C. Cowherd, Jr., F. Pendleton. "Calibration of a Cyclone for Monitoring Inhalable Particulate". *Jour. Environ. Engineering*, 112(3), pp. 468-478. 1986.

Cowherd, C., Jr., G. E. Muleski, P.J. Englehart, D.A. Gillette. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*. EPA/600/8-85/002. USEPA, Washington, DC. 1985.

Cowherd, Chatten, Jr. *Background Document for AP-42 Section 11.2.7 on Industrial Wind Erosion*. EPA Contract No. 68-02-4395, Midwest Research Institute. July 1988.

Cowherd, C. Jr., M.A. Grelinger, P.J. Englehart, R.F. Kent, K.F. Wong. Apparatus and Methodology for Predicting the Dustiness of Materials. *Am Ind. Hyg. Assoc. Jour.* (50), pp. 123-130. 1989.

Gillette, Dale. "Tests with a Portable Wind Tunnel for Determining Wind Erosion Threshold Velocities." *Atmos. Environ.* 12:2309. 1978.

Haines, P. Personal Communication. 2001.

Huntzicker, J.J., R.L. Johnson, J.J. Shah, R.A. Cary. "Analysis of Organic and Elemental Carbon in Ambient Aerosol by a Thermal-Optical Method," in *Particulate Carbon: Atmospheric Life Cycle*, pp 79-88. G.T. Wolff, R.L. Klimisch, Eds., Plenum Press, New York, NY. 1982.

Ower, E., R.C. Pankhurst. *The Measurement of Air Flow*. Pergamon Press, London. 1969.

U.S. Environmental Protection Agency. *National Technical Guidance Series Air Pathway Analysis Procedure for Superfund Applications*. Vol. II: *Estimates of Baseline Air Emissions at Superfund Sites*. EPA-450/1-89-002a. 1989.

U.S. Environmental Protection Agency. "Compilation of Air Pollutant Emissions Factors", AP-42. Fifth Edition, Supplements A-F, Volume I: *Stationary Point and Area Sources*. Research Triangle Park, NC. 2000.

Watson, J.G., J. Chow. "Particle and Gas Measurement on Filters," in *Sampling of Environmental Materials for Trace Analysis* (edited by B. Markert), pp. 83-115. VCH Publisher, Weinheim, New York, Tokyo. 1994.

# Appendix A

# Results of Gravimetric Analysis

**Table A-1. Cyclone Back-up Filter Weights (mg)**

| Date | Run no. | Filter no. | Tare weight | Final weight | Blank correction | Blank corrected net weight | Cyclone catch (g) | Filter/ Cyclone |
|---|---|---|---|---|---|---|---|---|
| 8/22/00 | CB-16 | 0012079 | 3590.30 | 3893.10 | −0.10 | 302.70 | 1.3979 | 0.2165 |
| 8/22/00 | CB-17 | 0012080 | 3633.65 | 3837.60 | −0.10 | 203.85 | 3.5295 | 0.0578 |
| 8/22/00 | CB-18 | 0012081 | 3673.35 | 3887.85 | −0.10 | 214.40 | 3.9298 | 0.0546 |
| 8/22/00 | CB-19 | 0012082 | 3638.00 | 3696.55 | −0.10 | 58.45 | 0.2765 | 0.2114 |
| 8/23/00 | CB-20 | 31 | 2759.5 | 2993.0 | −1.37 | 234.87 | 0.2453 | 0.9575 |
| 8/24/00 | CB-21 | 34 | 2754.1 | 3217.1 | −1.37 | 464.37 | 0.1523 | 3.0491 |
| 8/24/00 | CB-22 | 43 | 2779.8 | 2851.0 | −1.37 | 72.57 | 0.0426 | 1.7036 |
| 8/25/00 | CB-23 | 46 | 2808.8 | 2844.5 | −1.37 | 37.07 | 0.0113 | 3.2807 |

**Table A-2. Upwind/ Background Filter Weights (mg)**

| Date | Run no. | Filter no. | Tare weight | Final weight | Blank Correction | Blank corrected net weight | Duration (min) | Flow rate (cfm) |
|---|---|---|---|---|---|---|---|---|
| 8/22/00 | CB-16,17,18,19 | 0012078 | 3678.60 | 3686.35 | −0.10 | 7.65 | 136 | 40 |
| 8/23/00 | CB-20 | 33 | 2763.8 | 2868.2 | −1.37 | 105.77 | 138 | 40 |
| 8/24/00 | CB-21, 22 | 39 | 2740.7 | 2756.5 | −1.37 | 17.17 | 289 | 40 |
| 8/25/00 | CB-23 | 45 | 2725.8 | 2760.5 | −1.37 | 36.07 | 133 | 40 |

**Table A-3. Blank Filter weights (mg)**

| Date | Run no. | Filter no. | Tare weight | Final weight | Net weight |
|---|---|---|---|---|---|
| 8/22/00 | CB-16,17,18,19 | 0012083 | 3625.40 | 3625.15 | −0.25 |
| 8/22/00 | CB-16,17,18,19 | 0012084 | 3609.65 | 3609.70 | 0.05 |
| 8/23/00 | CB-20 | 32 | 2783.7 | 2783.7 | 0.00 |
| 8/24/00 | CB-21 | 35 | 2766.4 | 2767.5 | 1.10 |
| 8/24/00 | CB-22 | 44 | 2738.0 | 2735.2 | −2.80 |
| 8/25/00 | CB-23 | 47 | 2766.2 | 2764.0 | −2.20 |
| 8/23/00 | CB-20 | 36 | 2804.2 | 2803.8 | −0.40 |
| 8/24/00 | CB-22 | 42 | 2716.6 | 2713.7 | −2.90 |
| 8/25/00 | CB-23 | 48 | 2770.7 | 2768.3 | −2.40 |

Unpaved road average blank filter net weight = -0.10 mg.
Wildfire area average blank filter net weight = -1.37 mg.

# Appendix B
# Results of Soil Isotopic Analysis

## Table B-1. Soil Data

| Sample ID | Location | Number of samples composited[b] | Final sample volume (ml) | Size fraction, □m cut size | Mass fractions of loose soil[a] | Mass of bottled soil sample[c] (g) |
|---|---|---|---|---|---|---|
| 001.001 | 1 | 8 | 125 | <75 | 8.2% | 132.0 |
| 002.001 | 1 | 8 | 125 | 75-600 | 42.0% | 107.0 |
| 003.001 | 1 | 8 | 125 | >600 | 49.7% | 78.0 |
| 004.001 | 2 | 7 | 125 | <75 | 7.2% | 120.0 |
| 005.001 | 2 | 7 | 125 | 75-600 | 39.6% | 100.0 |
| 006.001 | 2 | 7 | 125 | >600 | 53.2% | 43.0 |
| 007.001 | 3 | 6 | 125 | <75 | 10.1% | 147.0 |
| 008.001 | 3 | 6 | 125 | 75-600 | 43.3% | 108.0 |
| 009.001 | 3 | 6 | 125 | >600 | 46.5% | 51.0 |
| 010.001 | 4 | 8 | 125 | <75 | 7.4% | 138.0 |
| 011.001 | 4 | 8 | 125 | 75-600 | 43.0% | 104.0 |
| 012.001 | 4 | 8 | 125 | >600 | 49.4% | 52.0 |

[a] For locations 2-4, mass of each size fraction was determined for one soil sample of the several composited. For location 1, the average of location 2-4 size ratios was used (no size ratio measurements performed for that batch).

[b] Soil was collected to 1.5 cm depth and then sieved using a #30 and #200 standard sieve, followed by a pan. Sieve volume limited sample size.

[c] Mass of soil sample in bottle, less bottle tare. Sample compression occurred during bottling.

## Table B-2. Analytical Data

| Sample ID | Location | Pu239/240 activity (pCi/g) | Total error (pCi/g) | MDA (pCi/g) |
|---|---|---|---|---|
| 001.001 | 1 | 2.09 | 0.683 | 0.130 |
| 002.001 | 1 | 2.23 | 0.718 | 0.131 |
| 003.001 | 1 | 1.03 | 0.421 | 0.135 |
| 004.001 | 2 | 0.94 | 0.393 | 0.183 |
| 005.001 | 2 | 1.54 | 0.553 | 0.190 |
| 006.001 | 2 | 0.85 | 0.365 | 0.074 |
| 007.001 | 3 | 2.37 | 0.752 | 0.130 |
| 008.001 | 3 | 2.20 | 0.703 | 0.148 |
| 009.001 | 3 | 1.78 | 0.612 | 0.157 |
| 010.001 | 4 | 1.66 | 0.595 | 0.143 |
| 011.001 | 4 | 2.40 | 0.779 | 0.141 |
| 012.001 | 4 | 1.43 | 0.514 | 0.128 |

## Table B-3. Isotopic Summary

| Sample ID | Location | Pu239/240 (pCi/g) | Am241 (pCi/g) | Pu239/Am241 Ratio | U234 (pCi/g) | U235 (pCi/g) | U238 (pCi/g) | U234/U238 Ratio |
|---|---|---|---|---|---|---|---|---|
| 001.001 | 1 | 2.09 | 0.88 | 2.4 | 1.62 | 0.25 | 1.28 | 1.3 |
| 002.001 | 1 | 2.23 | 0.35 | 6.4 | 0.99 | 0.39 | 1.49 | 0.7 |
| 003.001 | 1 | 1.03 | 0.23 | 4.5 | 0.85 | 0.23 | 0.84 | 1.0 |
| 004.001 | 2 | 0.94 | 0.20 | 4.6 | 1.64 | 0.41 | 1.65 | 1.0 |
| 005.001 | 2 | 1.54 | 0.45 | 3.4 | 1.03 | 0.16 | 0.76 | 1.3 |
| 006.001 | 2 | 0.85 | 0.47 | 1.8 | 0.71 | 0.09 | 0.73 | 1.0 |
| 007.001 | 3 | 2.37 | 0.70 | 3.4 | 1.02 | 0.15 | 1.24 | 0.8 |
| 008.001 | 3 | 2.20 | 0.55 | 4.0 | 0.69 | 0.27 | 1.18 | 0.6 |
| 009.001 | 3 | 1.78 | 0.25 | 7.2 | 0.64 | 0.15 | 0.51 | 1.3 |
| 010.001 | 4 | 1.66 | 0.47 | 3.5 | 0.96 | 0.17 | 1.25 | 0.8 |
| 011.001 | 4 | 2.40 | 0.38 | 6.3 | 1.42 | 0.10 | 1.31 | 1.1 |
| 012.001 | 4 | 1.43 | 0.36 | 4.0 | 0.86 | 0.16 | 0.63 | 1.4 |

# Appendix C

# Results of Filter and Cyclone Catch Isotopic Analysis

## Table C-1. Filter Data

| Sample ID | Location | Run no. | Filter no. |
|---|---|---|---|
| 001.001 | CB-20-1 | CB-20 | 31 |
| 002.001 | CB-20,21-BKG | CB-20 background | 33 |
| 003.001 | CB-21-1 | CB-21 | 34 |
| 004.001 | CB-22-1 | CB-22 | 43 |
| 005.001 | CB-22,23-BKG | CB-21,22 background | 39 |
| 006.001 | CB-23-1 | CB-23 | 46 |
| 007.001 | CB-24,25-BKG | CB-23 background | 45 |

## Table C-2. Filter Analysis Data

| Sample ID | Pu239/240 activity (dpm) | Total error (dpm) | MDA (dpm) |
|---|---|---|---|
| 001.001 | 0.621 | 0.177 | 0.048 |
| 002.001 | 0.463 | 0.157 | 0.053 |
| 003.001 | 1.910 | 0.462 | 0.050 |
| 004.001 | 0.174 | 0.046 | 0.049 |
| 005.001 | 0.004 | 0.025 | 0.047 |
| 006.001 | 0.054 | 0.041 | 0.046 |
| 007.001 | 0.061 | 0.051 | 0.049 |

## Table C-3. Filter Isotopic Summary

| Sample ID | Pu239/240 (dpm) | Pu238 (dpm) | Am241 (dpm) | U233/234 (dpm) | U235 (dpm) | U238 (dpm) |
|---|---|---|---|---|---|---|
| 001.001 | 0.621 | 0.021 | 0.165 | 0.301 | 0.021 | 0.372 |
| 002.001 | 0.463 | 0.041 | 0.070 | 0.562 | 0.041 | 0.587 |
| 003.001 | 1.910 | 0.010 | 0.402 | 0.705 | -0.012 | 0.782 |
| 004.001 | 0.174 | -0.003 | 0.045 | 0.148 | 0.015 | 0.093 |
| 005.001 | 0.004 | -0.004 | -0.010 | -0.015 | 0.003 | 0.141 |
| 006.001 | 0.054 | -0.004 | 0.010 | 0.162 | 0.033 | 0.182 |
| 007.001 | 0.061 | -0.007 | 0.010 | 0.037 | 0.000 | 0.126 |

Table C-4. Cyclone Catch Data

| Sample ID | Location | Run no. |
|---|---|---|
| 008.001 | CB-20-A1 | CB-20 |
| 009.001 | CB-21-A1 | CB-21 |
| 010.001 | CB-22-A1 | CB-22 |
| 011.001 | CB-23-A1 | CB-23 |

Table C-5. Cyclone Catch Analysis

| Sample ID | Pu239/240 activity (pCi/g) | Total error (pCi/g) | MDA (pCi/g) |
|---|---|---|---|
| 008.001 | 2.140 | 0.526 | 0.021 |
| 009.001 | 1.930 | 0.534 | 0.101 |
| 010.001 | 1.200 | 0.518 | 0.116 |
| 011.001 | 2.430 | 1.500 | 0.549 |

Table C-6. Cyclone Catch Isotopic Summary

| Sample ID | Pu239/240 (dpm) | Am241 (dpm) | U233/234 (dpm) | U235 (dpm) | U238 (dpm) |
|---|---|---|---|---|---|
| 008.001 | 2.140 | 0.370 | 1.370 | 0.038 | 1.250 |
| 009.001 | 1.930 | 0.525 | 2.040 | 0.124 | 2.080 |
| 010.001 | 1.200 | 0.566 | 3.460 | 0.090 | 3.770 |
| 011.001 | 2.430 | 3.170 | 11.600 | 0.566 | 9.280 |

# Appendix D

# CB-22 Example Calculation

## Part I: Calculation of tunnel effluent concentrations

- Duration of testing:

| | | | | | |
|---|---|---|---|---|---|
| CB-22A | = | 20 min | CB-22D | = | 22 min |
| CB-22B | = | 21 min | CB-22E | = | 21 min |
| CB-22C | = | 21 min | CB-22F | = | 21 min |

**Total for CB-22 = 126 min**

- Blank-corrected effluent filter net weight:
  Tare weight = 2779.8 mg
  Final weight = 2851.0 mg
  Blank correction = -1.37 mg
  Filter net weight = 72.57 mg
  *Net weight constitutes PM-10 mass collected by effluent sampler

- Effluent sampler flow rate = 40 cfm = 1.13267 $m^3$/min

**Average effluent PM-10 concentration:**

$$\frac{72.57 \text{ mg}}{1.13267 \text{ m}^3/\text{min} \times 126 \text{ min}} = 0.508 \text{ mg/m}^3$$

- Blank-corrected inlet filter net weight:
  Tare weight = 2740.7 mg
  Final weight = 2756.5 mg
  Blank correction = -1.37 mg
  Filter net weight = 17.17 mg
  *Net weight constitutes TSP mass collected by inlet sampler
  *Based on historical data, 38.95% of TSP mass assumed to be PM-10 mass collected from ambient air
  PM-10 mass collected = 6.688 mg

- Duration of inlet sampling = 289 min
- Inlet sampler flow rate = 40 cfm = 1.13267 $m^3$/min

**Inlet PM-10 concentration:**

$$\frac{6.688 \text{ mg}}{1.13267 \text{ m}^3/\text{min} \times 289 \text{ min}} = 0.020 \text{ mg/m}^3$$

**Net PM-10 concentration (attributable to emissions from test area):**

$0.508 \text{ mg/m}^3 - 0.020 \text{ mg/m}^3 = 0.488 \text{ mg/m}^3$

- Cyclone catch (sieved to remove particles with diameters greater then 45 μm [#325 screen]):
  Bag tare weight = 3.6340 g
  Bag final weight = 3.6766 g
  Bag net weight = 0.0426 g = 42.6 mg
  *Sample collected in bag represents suspended particles greater than 10 μm aerodynamic diameter and less than 45 μm physical diameter, i.e., approximately TSP – PM-10

The mass of the sieved cyclone catch must be adjusted for non-isokinetic flow conditions. The adjustment is based on the isokinetic flow ratio (IFR) which is defined as the intake air velocity of the sampling nozzle divided by the approach air velocity at the centerline of the effluent tube (sampling extension). PM-10 has negligible inertial characteristics and requires no correction for non-isokinetic sampling.

- Isokinetic flow ratio (IFR) at maximum wind speed (which contributes most of the sieved cyclone catch) = 4.93

- Adjusted cyclone catch:
  IFR adjusted mass (TSP - PM-10) = 42.6 x 4.93 = 210.02 mg

**Average effluent TSP concentration:**

$$\frac{72.57\text{ mg} + 210.02\text{ mg}}{1.13267\text{ m}^3/\text{min} \times 126\text{ min}} = 1.980\text{ mg/m}^3$$

**Inlet TSP concentration:**

$$\frac{17.17\text{ mg}}{1.13267\text{ m}^3/\text{min} \times 289\text{ min}} = 0.052\text{ mg/m}^3$$

**Net TSP concentration (attributable to emissions from test area):**

$1.980\text{ mg/m}^3 - 0.052\text{ mg/m}^3 = 1.928\text{ mg/m}^3$

**Part II: Calculation of erosion potentials**

- Average maximum $\Delta p$ for pitot tube at centerline (CL) of working section during test runs:
  CB-22A = 0.33 in. $H_2O$
  CB-22B = 0.36 in. $H_2O$
  CB-22C = 0.27 in. $H_2O$
  CB-22D = 0.25 in. $H_2O$
  CB-22E = 0.25 in. $H_2O$
  CB-22F = 0.23 in. $H_2O$
  CB-22= 0.28 in. $H_2O$ (average)

- Factor for conversion of $\Delta p$ to wind speed (mph):
  Average barometric pressure = 24.8 in. Hg
  Ambient temperature = 84°F

$$K' = 10.83 \times \left( \frac{(84°F + 459.3)}{24.8 \text{ in. Hg}} \right)^{1/2} = 50.69$$

**Maximum wind speed (mph) at tunnel CL:**

$$50.69 \times (0.28 \text{ in. } H_2O)^{1/2} = 26.8 \text{ mph}$$

- Tunnel CL height = 7.62 cm
- Surface roughness height for test surface = 1.21 cm
  * Estimated from velocity profile during run CB-23F

**Equivalent maximum wind speed (mph) at 10-m height:**

$$\frac{26.8 \text{ mph} \times \ln \frac{1000 \text{ cm}}{1.21 \text{ cm}}}{\ln \frac{7.62 \text{ cm}}{1.21 \text{ cm}}} = 97.5 \text{ mph}$$

**Corresponding friction velocity:**

$$\frac{26.8 \text{ mph} \times 0.4}{\ln \frac{7.62 \text{ cm}}{1.21 \text{ cm}}} = 5.83 \text{ mph} = 259.6 \text{ cm/s}$$

**Net PM-10 mass collected:**

$$\frac{72.57 \text{ mg}}{4.93} - \left(6.688 \text{ mg x } \frac{126 \text{ min}}{289 \text{ min}}\right) = 11.80 \text{ mg } = 0.0118 \text{ g}$$

*Inlet mass time-weighted to effluent sampler run time

*PM-10 mass oversampled, adjust for IFR

- Ratio of effluent tube area to intake nozzle area:
  Effluent tube i.d. = 7.874 in  Effluent tube area = 48.69 $in^2$
  Intake nozzle i.d. = 0.88 in  Intake nozzle area = 0.608 $in^2$
  Area ratio = 80.08

- Exposed test surface area dimensions = 8 ft x 6 in
- Area of ground surface sampled = 4 $ft^2$ = 0.3716 $m^2$

**PM-10 erosion potential/loss:**

$$\frac{0.0118 \text{ g x } (80.08 \text{ x } 85\%)}{6 \text{ x } 0.3716 \text{ m}^2} = 0.36 \text{ g/m}^2$$

*Six test areas sampled during CB-22

*85% of the centerline wind speed is the average wind speed across the area of the effluent tube (sampling extension)

**TSP erosion potential/loss:**

$$\frac{(0.0118 \text{ g} + 0.0426 \text{ g}) \text{ x } (80.08 \text{ x } 85\%)}{6 \text{ x } 0.3716 \text{ m}^2} = 1.52 \text{ g/m}^2$$

*Six test areas sampled during CB-22

*85% of the centerline wind speed is the average wind speed across the area of the effluent tube (sampling extension)

**Part III: Calculation of tunnel effluent Pu239 activity levels and concentrations**

The first calculation method relies on the amount of air sampled ($m^3$) and the total activity (pCi) to find the activity level per volume of air ($pCi/m^3$). This concentration is found for both the effluent and inlet samples, and the net effluent Pu239 concentration is determined by subtracting the inlet concentration from the effluent concentration.

- Duration of effluent sampling = 126 min
- Duration of inlet sampling = 289 min

- Volume of air sampled by effluent sampler:
  40 cfm x 126 min = 5040 $ft^3$ = 142.7 $m^3$
- Volume of air sampled by inlet sampler:
  40 cfm x 289 min = 11560 $ft^3$ = 327.3 $m^3$

- Tunnel effluent filter Pu239 activity (PM-10) = 0.174 dpm
- Tunnel inlet filter Pu239 activity (TSP) = 0.004 dpm
- Tunnel inlet PM-10 Pu239 activity (assuming that Pu239 activity is not dependent on particle size in the TSP size range):

  0.004 dpm x 0.3895 = 0.00156 dpm

- Conversion factor: 1 pCi = 2.2 disintegrations per min (dpm)

**Tunnel effluent Pu239 concentration (PM-10):**

$$\frac{0.174 \text{ dpm} \times 0.45 \text{ pCi/dpm}}{142.7 \text{ m}^3} = 0.00055 \text{ pCi/m}^3$$

**Tunnel inlet Pu239 concentration (PM-10):**

$$\frac{0.00156 \text{ dpm} \times 0.45 \text{ pCi/dpm}}{327.3 \text{ m}^3} = 0.00000214 \text{ pCi/m}^3$$

**Pu239 concentration attributed to PM-10 eroded from soil:**

$$0.00055 \text{ pCi/m}^3 - 0.00000214 \text{ pCi/m}^3 = 0.0005479 \text{ pCi/m}^3$$

As shown above the tunnel inlet air contributes only 0.2% of the Pu239 activity found in the effluent air.

The fraction of TSP above PM-10 must be adjusted for non-isokinetic flow conditions. PM-10 as negligible inertial characteristics and requires no correction for non-isokinetic sampling.

- Tunnel effluent mass (TSP - PM-10) = 42.6 mg
- Isokinetic flow ratio (IFR) at maximum wind speed = 4.93
  * TSP mass sampled under non-isokinetic conditions, must be adjusted by IFR ratio

  IFR adjusted mass (TSP - PM-10) = 42.6 x 4.93 = 210.02 mg

- Volume of air sampled by effluent sampler:
  40 cfm x 126 min = 5040 $ft^3$ = 142.7 $m^3$
- Volume of air sampled by inlet sampler:
  40 cfm x 289 min = 11560 $ft^3$ = 327.3 $m^3$

- Tunnel effluent Pu239 activity (TSP - PM-10)= 1.200 pCi/g = 0.0012 pCi/mg
- Tunnel inlet Pu239 activity (TSP) = 0.004 dpm

**Tunnel effluent concentration (TSP - PM-10):**

$$\frac{210.02\ \text{mg}}{142.7\ \text{m}^3} = 1.47\ \text{mg/m}^3$$

**Tunnel effluent Pu239 concentration (TSP - PM-10):**

$0.0012\ \text{pCi/mg} \times 1.47\ \text{mg/m}^3 = 0.0018\ \text{pCi/m}^3$

- Tunnel effluent Pu239 concentration(PM-10) = 0.00055 $pCi/m^3$ from previous calculation

**Tunnel effluent Pu239 concentration (TSP = PM-10 + [TSP - PM-10]):**

$0.0018\ \text{pCi/m}^3 + 0.00055\ \text{pCi/m}^3 = 0.0023\ \text{pCi/m}^3$

**Tunnel inlet Pu239 concentration (TSP):**

$$\frac{0.004\ \text{dpm/filter} \times 0.45\ \text{pCi/dpm}}{327.3\ \text{m}^3\text{/filter}} = 0.0000055\ \text{pCi/m}^3$$

**Pu239 concentration attributed to TSP eroded from soil:**

$0.0023\ \text{pCi/m}^3 - 0.0000055\ \text{pCi/m}^3 = 0.002309\ \text{pCi/m}^3$

## Alternative Calculation

The alternative calculation method relies on the net particulate concentration (mg/m$^3$) and the net Pu239 activity level (pCi/mg) to find the Pu239 concentration (pCi/m$^3$). The net mass (mg) and the net Pu239 specific activity (pCi) are used to find the concentrations and activity levels.

- Duration of testing = 126 min
- Blank-corrected tunnel effluent mass (PM-10) = 72.57 mg = 0.07257 g
- Duration of inlet sampling = 289 min
- Blank-corrected tunnel inlet mass (TSP)= 17.17 mg
- Blank-corrected tunnel inlet mass (PM-10) = 6.688 mg
- Time-weighted blank-corrected tunnel inlet mass (PM-10 background mass for test time only):

$$6.688 \text{ mg x } \frac{126 \text{ min}}{289 \text{ min}} = 2.916 \text{ mg} = 0.0029 \text{ g}$$

**Net tunnel effluent mass (PM-10):**

72.57 mg – 2.916 mg = 69.66 mg = 0.06966 g

- Volume of air sampled by effluent sampler:
  40 cfm x 126 min = 5040 ft$^3$ = 142.7 m$^3$

**Net effluent concentration (PM-10):**

$$\frac{69.66 \text{ mg}}{142.7 \text{ m}^3} = 0.488 \text{ mg/m}^3 = 0.000488 \text{ g/m}^3$$

- Tunnel effluent Pu239 activity = 0.174 dpm
- Tunnel inlet Pu239 activity = 0.004 dpm

**Tunnel effluent Pu239 activity (PM-10):**

$$\frac{0.174 \text{ dpm x } 0.45 \text{ pCi/dpm}}{0.07257 \text{ g}} = 1.08 \text{ pCi/g}$$

1.08 pCi/g x 0.07257 g = 0.078 pCi

**Tunnel inlet Pu239 activity (PM-10):**

$$\frac{0.004 \text{ dpm/filter x } 0.45 \text{ pCi/dpm}}{0.01717 \text{ g}} = 0.10 \text{ pCi/g}$$

$0.10 \text{ pCi/g} \times 0.002916 \text{ g} = 0.000306 \text{ pCi}$

**Net Pu239 activity (PM-10):**

$0.078 \text{ pCi} - 0.000306 \text{ pCi} = 0.0780 \text{ pCi}$

$$\frac{0.0780 \text{ pCi}}{0.06966 \text{ g}} = 1.12 \text{ pCi/g}$$

**Pu239 concentration attributed to PM-10 eroded from soil:**

$1.12 \text{ pCi/g} \times 0.000488 \text{ g/m}^3 = 0.00055 \text{ pCi/m}^3$

- Tunnel effluent mass (TSP - PM-10) = 42.6 mg
- Isokinetic flow ratio (IFR) at maximum wind speed = 4.93
  * TSP mass sampled under non-isokinetic conditions, must be adjusted by IFR ratio

  IFR adjusted mass (TSP - PM-10) = 42.6 x 4.93 = 210.02 mg

- Tunnel effluent mass (TSP):
  210.02 mg + 72.57 mg = 282.59 mg
- Blank-corrected tunnel inlet mass (TSP) = 17.17 mg = 0.01717 g
- Time-weighted blank-corrected tunnel inlet mass (TSP):

$$17.17 \text{ mg} \times \frac{126 \text{ min}}{289 \text{ min}} = 7.49 \text{ mg} = 0.00749 \text{ g}$$

**Net tunnel effluent mass (TSP):**

$282.59 \text{ mg} - 7.49 \text{ mg} = 275.10 \text{ mg} = 0.27510 \text{ g}$

- Volume of air sampled by effluent sampler:
  $40 \text{ cfm} \times 126 \text{ min} = 5040 \text{ ft}^3 = 142.7 \text{ m}^3$

**Net TSP concentration:**

$$\frac{275.10 \text{ mg}}{142.7 \text{ m}^3} = 1.928 \text{ mg/m}^3 = 0.001928 \text{ g/m}^3$$

- Tunnel effluent Pu239 activity (PM-10) = 0.078 pCi from previous calculation
- Tunnel effluent Pu239 activity (TSP - PM-10) = 1.200 pCi/g

**Tunnel effluent Pu239 activity (TSP):**

(1.200 pCi/g x 0.21002 g) + 0.078 pCi = 0.330 pCi

- Tunnel inlet Pu239 activity (TSP) = 0.004 dpm/ filter

**Tunnel inlet Pu239 activity (TSP):**

$$\frac{0.004 \text{ dpm/filter x } 0.45 \text{ pCi/dpm}}{0.01717 \text{ g/filter}} = 0.10 \text{ pCi/g}$$

0.10 pCi/g x 0.00749 g = 0.000785 pCi

**Net Pu239 activity (TSP):**

0.320 pCi – 0.000785 pCi = 0.330 pCi

$$\frac{0.330 \text{ pCi}}{0.27510 \text{ g}} = 1.198 \text{ pCi/g}$$

**Pu239 concentration attributed to TSP eroded from soil:**

1.198 pCi/g x 0.001928 g/m$^3$ = 0.002309 pCi/m$^3$

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